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Title: Modeling Fuel/Shell Mixing in Asymmetrically Driven Direct Drive ICF Implosions (U)

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The turbulent mixing model of Scannapieco and Cheng (Phys. Lett. A **299**, 49-64, 2002), can use a single mixing length parameter, α, to calculate the time and spatially dependent mixing between shell and fuel in ICF capsules. Its physical interpretation is the ratio of turbulent eddy size to thickness of the mixed region. The mix model has previously only been applied to spherical implosions. We designed and executed an experiment on the Omega laser with controlled drive asymmetry to test whether α changes with $L=2$ spherical harmonic asymmetry. Preliminary experimental results suggest that both prolate and oblate implosions require the same value of α as the spherical implosion. The DT burn temperature, measured from the neutron Doppler broadening, does not appear to depend upon the asymmetry, but rather on the value of α. Observed neutron and high energy X-ray images agree with those post-processed from calculations and also suggest the presence of mix. This work was performed under the auspices of DOE under contractW-7405-ENG-36. (u)

Modeling Fuel/Shell Mixing in Asymmetrically Driven Direct Drive ICF Implosions

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The effects of mixing are apparent in yield degradation, burn temperature, X-ray and neutron images.

- **The Scannapieco and Cheng, 2002 mix model**
- **Earlier controlled asymmetric implosions (Delamater et al, 1996, Smalyuk, Marshall, McKenty (LLE), unpublished)**
- **Yield degradation in symmetric and asymmetric implosions**
- **Burn temperatures**
- **X-ray Images (5-7keV)**
- **Neutron Images**

The introduction of a collision frequency ν between ion species leads to hydrodynamic equations for separate component velocities and densities.

- The momentum equation for each component is modified by including a collisional drag frequency υ_{ij} between components. (Cheng and Scannapieco, LA-UR-02-0194, 2002).

$$\rho \frac{d}{dt}\left(\frac{\rho_i}{\rho}(\mathbf{u_i}-\mathbf{u})\right)+\sum_j \frac{\rho_i\rho_j}{\rho}\nu_{ij}(\mathbf{u}_i-\mathbf{u}_j)=-\rho_i(\mathbf{u_i}-\mathbf{u})\cdot\nabla\mathbf{u}-\nabla\cdot P_i+\frac{\rho_i}{\rho}\nabla\cdot P$$

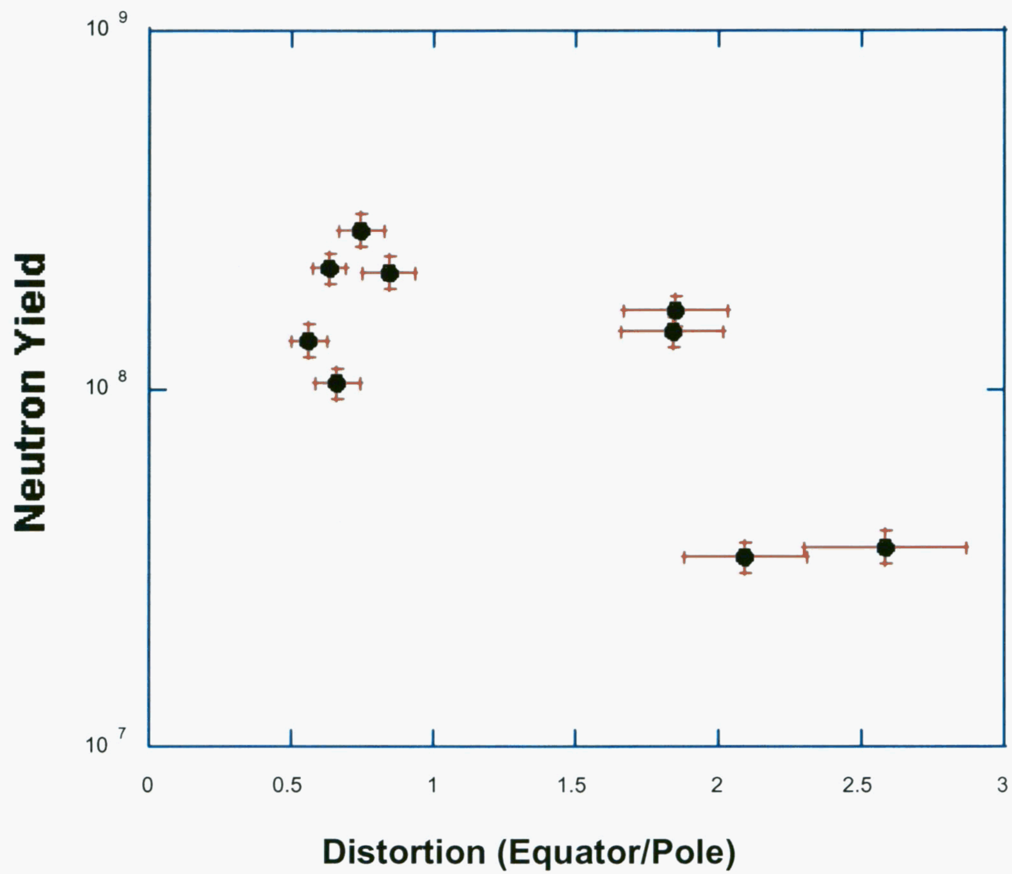
where $$\upsilon_{12}\equiv\frac{C_{12}}{\Lambda+\alpha\int|u_1-u_2|dt}$$

α is an experimentally determined constant and $\int|u_1-u_2|dt$ represents the thickness of the mix layer.
and Λ is the collision length from S.I.Braginski, 1965 and L. Spitzer, 1962.
It has been observed in various turbulent systems that the ratio of the mixing length to the width of the mixing layer, α, ranges from 0.07 to 0.125 (Launder and Spalding, 1972).

- For a capsule with a compressed fuel at $\rho \approx 40$ g/cm^3, T $\approx$0.8 keV, P $\approx$ 25 G bar $C_s \approx 2\ 10^7$ cm/s $\Lambda \approx 0.001$ μm and, with α=0, $\nu \approx 5\ 10^{14}$ /s

An experiment to test the combination of asymmetry and mixing was suggested by previous observations of yield decrease with asymmetry.

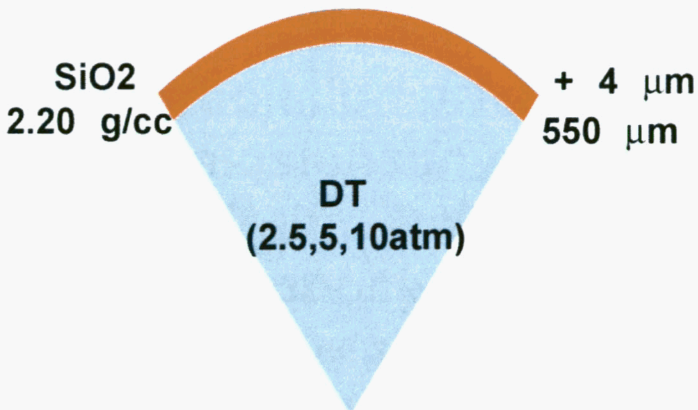
- X-radiation driven implosions in a NOVA hohlraum were used to diagnose laser beam pointing.
- No calculations were made of asymmetric yield.
- Delamater et al., Phys. Plasmas, 3, 2022-2028, 1996



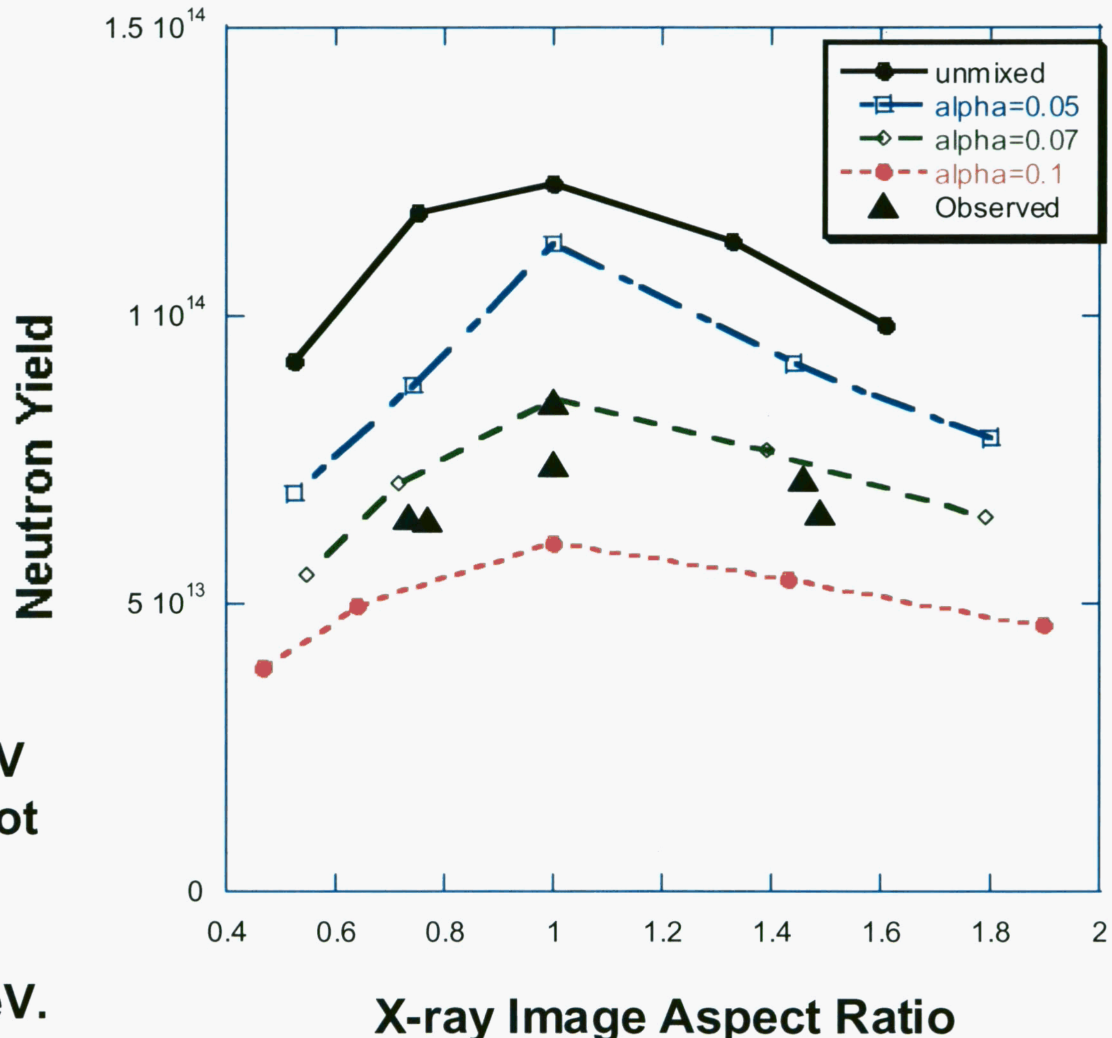
1 and 2 Dimensional computer simulations were used to calculate experimental X-ray and neutron observables.

- One burn history (NTD) measurement on a DD implosion provided absolute timing between the laser pulse and implosions and constrained the modeling.
- 1D simulations used non-radial rays, approximating the actual angular and power distribution on the capsule.
- 2D simulations used radial rays with reduced laser power(~0.83) and specified *L=2* asymmetries.
- All implosions used a electron flux limiter of 0.052.
- Calculated 2D images have not yet been convolved with experimental resolutions (~7μm for X-rays and ~20 μm for neutrons).
- The GDP process glass capsules contain ~0.3 atm of nitrogen which must be included in the calculations. Without it unmixed yields would be several times higher, but mixed yields modeling the experiment are little changed. (Nitrogen acts like a little mixing).

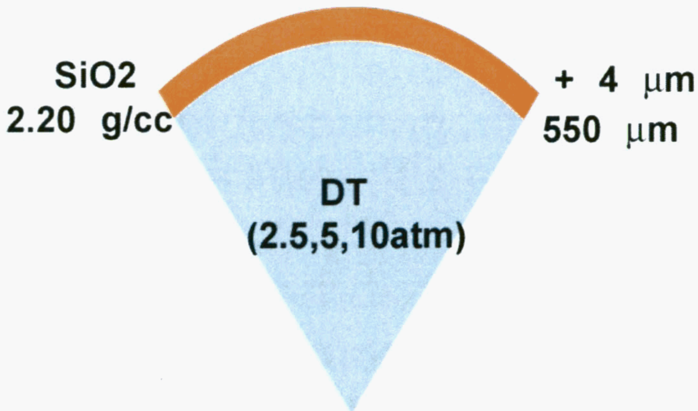
Observed yields are consistent with an alpha of ~0.07-0.08 for both the symmetric and asymmetric drives with 10 atm fill.

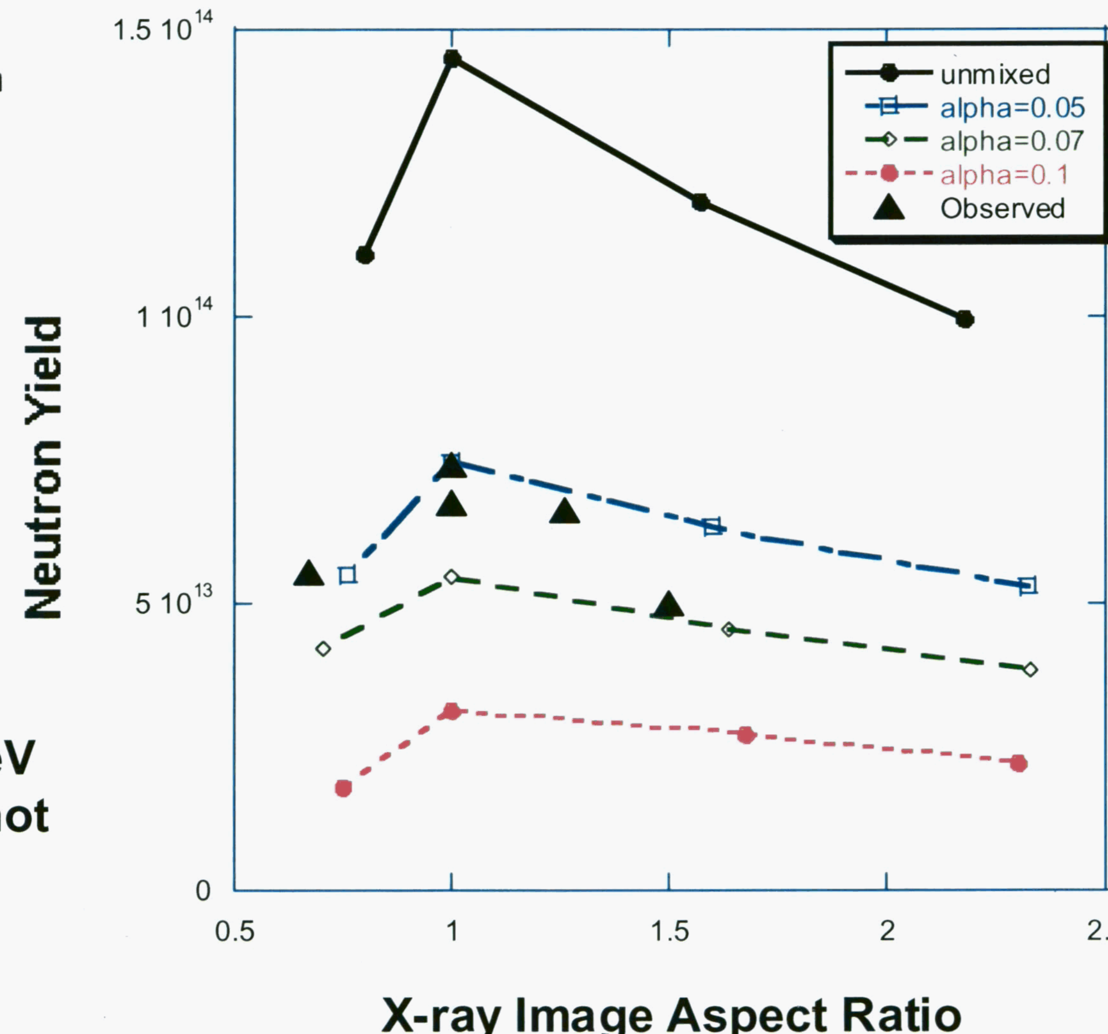


- 24-25 kJ Direct Drive
- 1ns square laser pulse.
- Calculated fuel ion temperatures (from 14 MeV Doppler broadening) do not change with asymmetry, only with alpha.
- Observed were 8.3 ±0.5 keV.



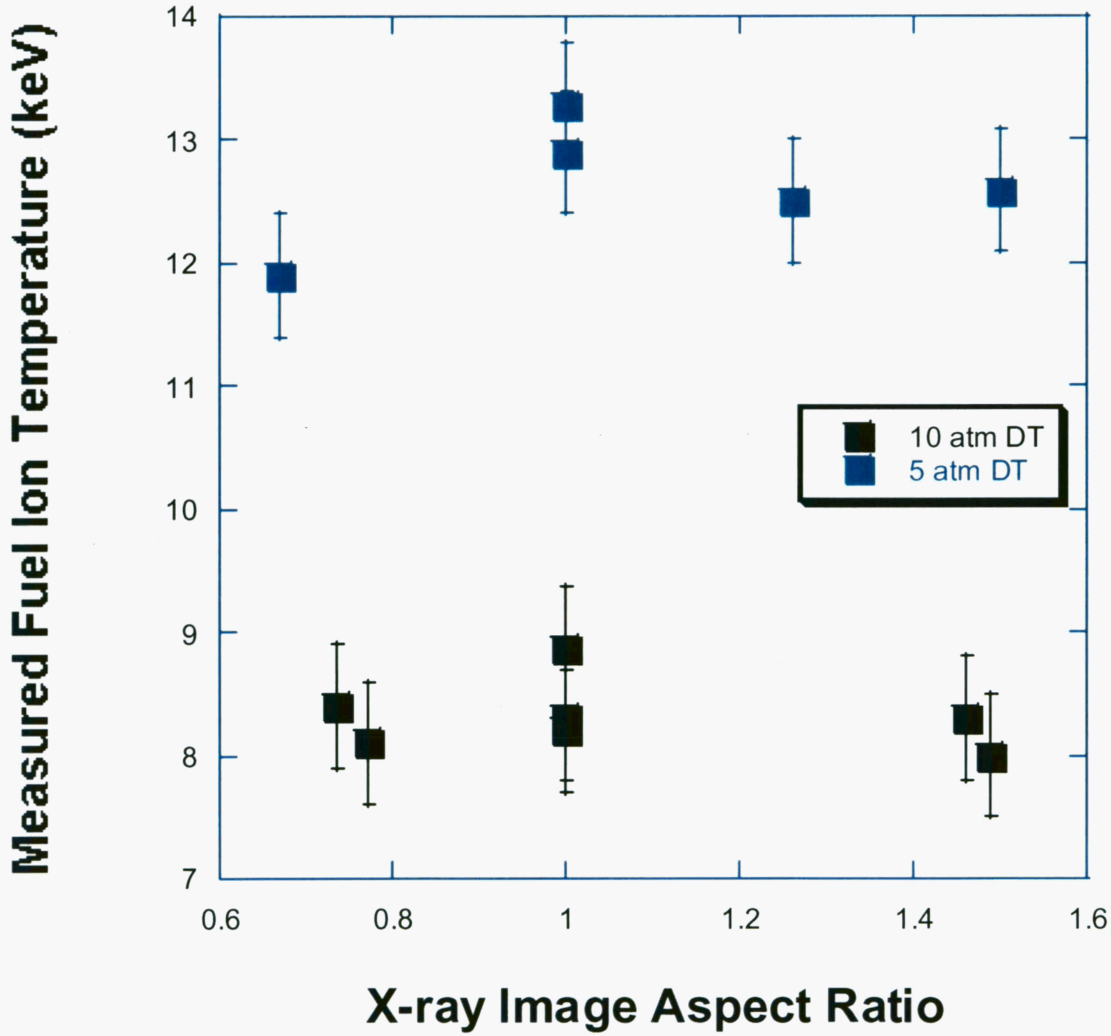
Observed yields are consistent with an alpha of ~0.05-0.07 for both the symmetric and asymmetric drives with 5 atm fill.





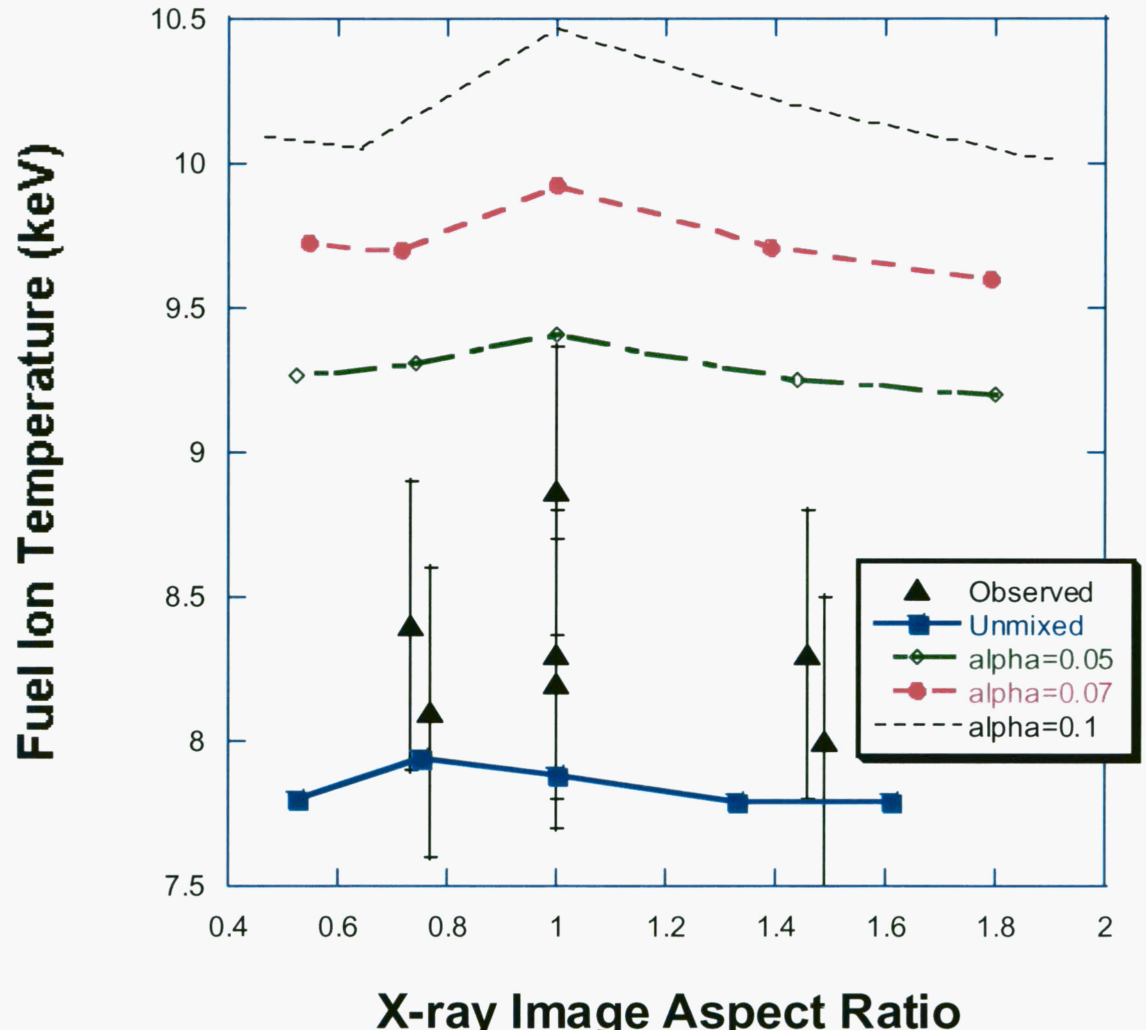
- 24-25 kJ Direct Drive
- 1ns square laser pulse.
- Calculated fuel ion temperatures (from 14 MeV Doppler broadening) do not change with asymmetry, only with alpha.
- Observed were 12.6 ±0.7 keV.

Measured Fuel Ion Temperatures are nearly independent of measured asymmetry



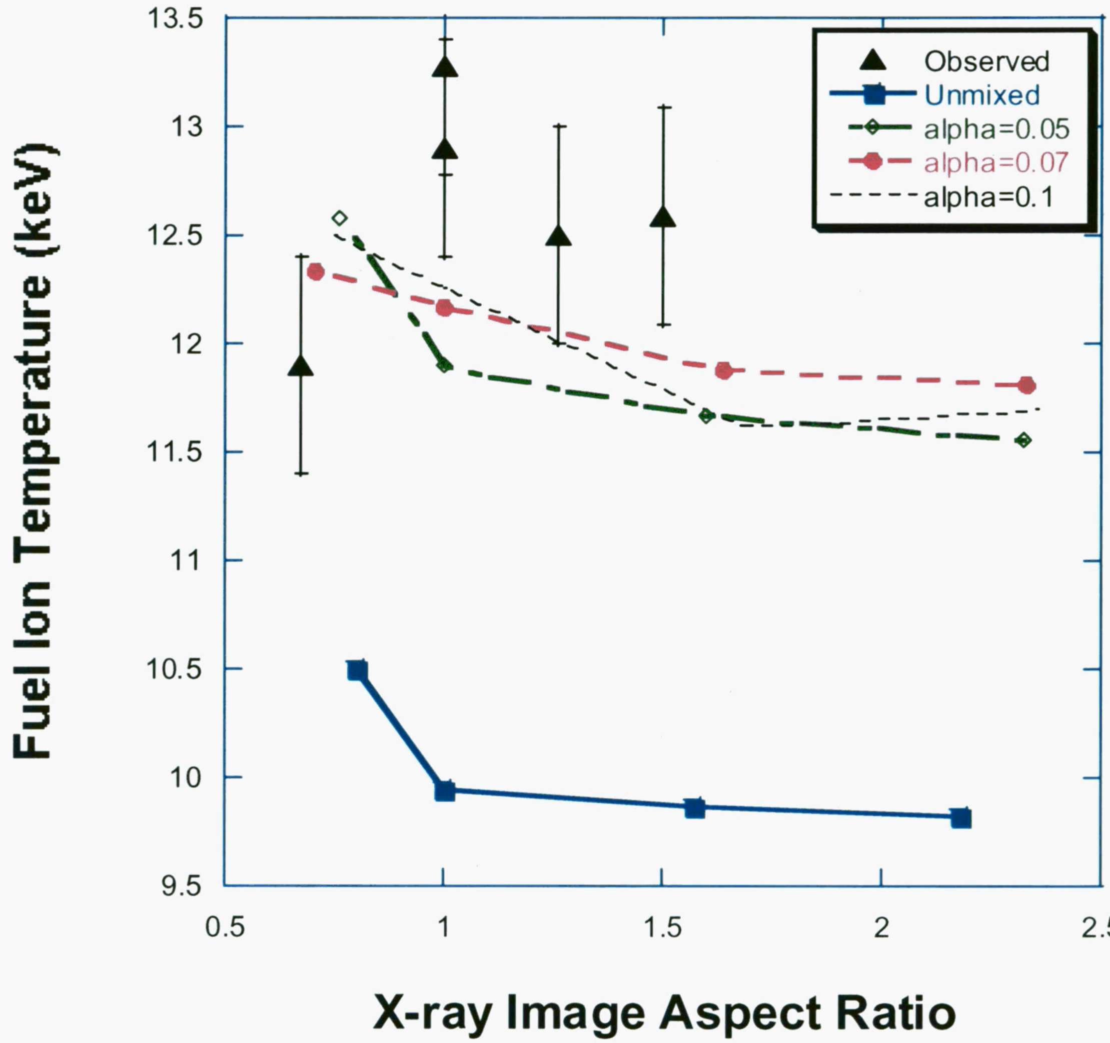
Measured fuel temperatures higher than clean calculated suggest mixing for the 10 atm filled capsules.

- **This capsule filled with 10 atm DT and convergence ratio of ~ 10 has only light mixing (yield degraded to ~64% of unmixed), the ion temperature is very sensitive the alpha, or the mixing length at compression.**

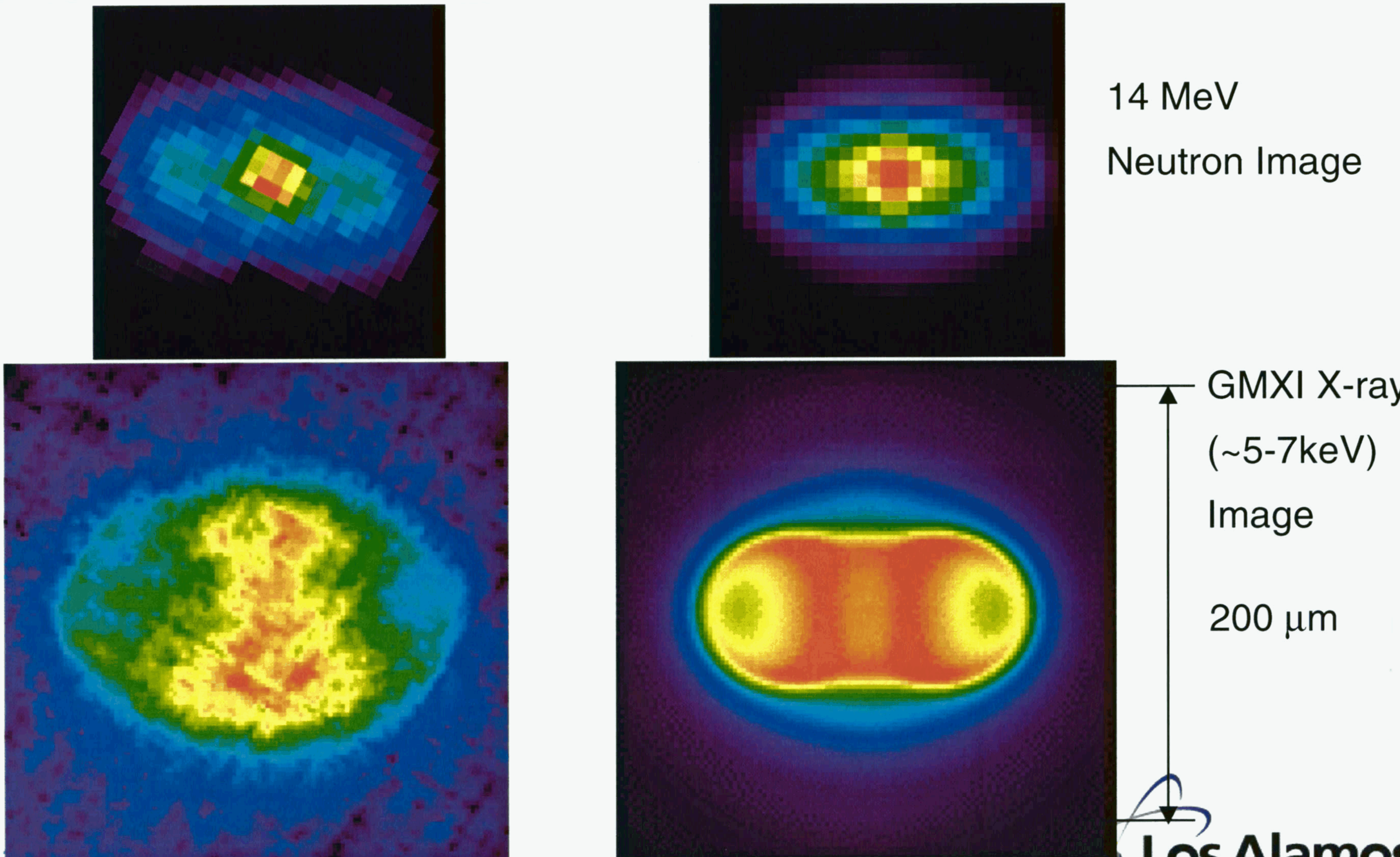


Measured fuel temperatures higher than clean calculated suggest mixing for the 5 atm filled capsules.

- **This capsule filled with 5 atm DT and convergence ratio of ~ 12 has heavier mixing (yield degraded to ~47% of unmixed), the ion temperature seems to reach a limiting value, less sensitive to α or the mixing length at final compression.**

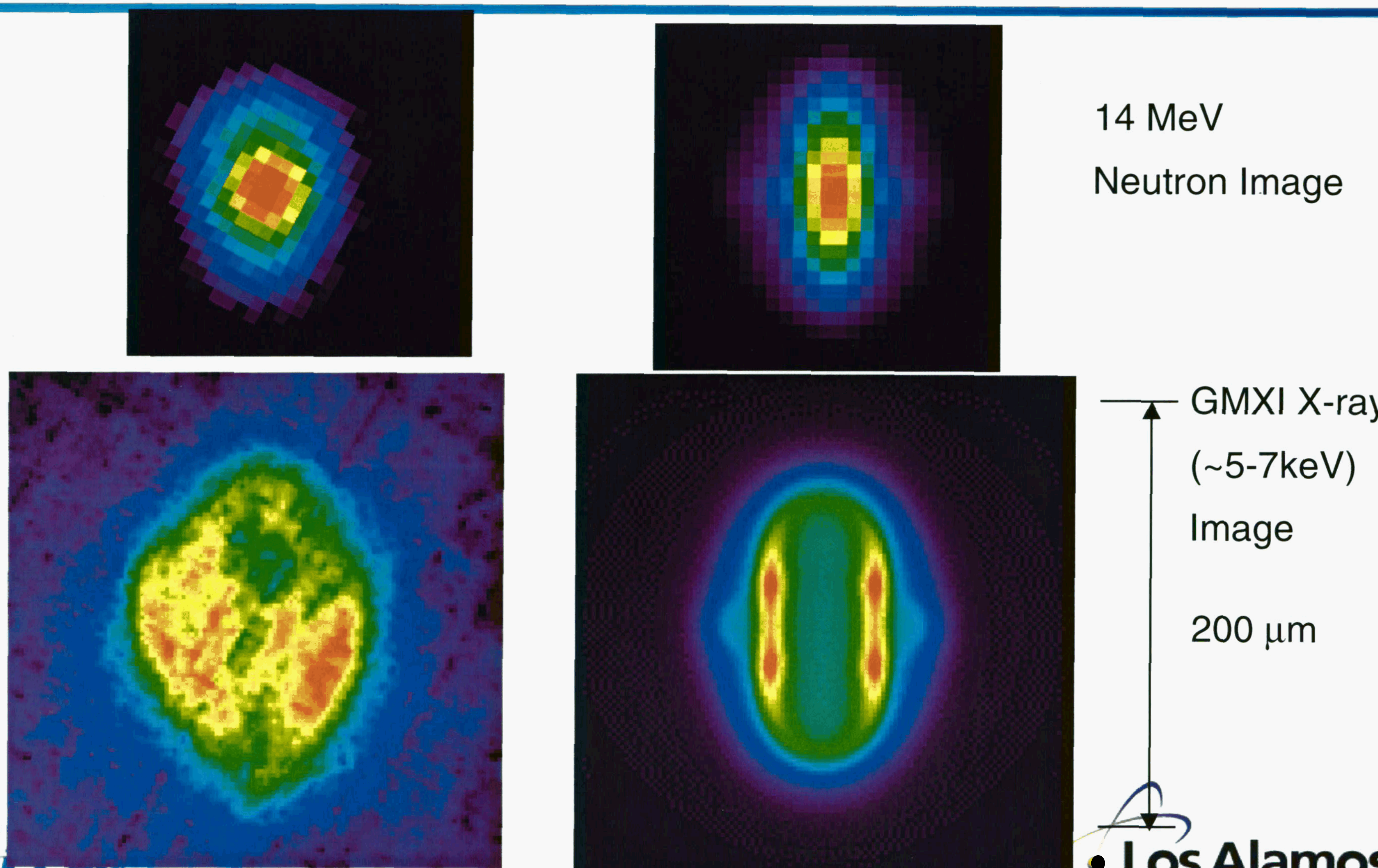


X-ray and neutron images agree in size and shape with predictions including mix (shot 26665 prolate implosion shown here).



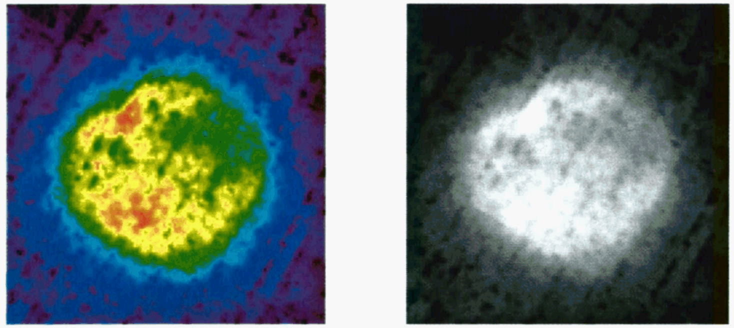
Calculated images are convolved with a gaussian system psf

X-ray and neutron images agree in size and shape with predictions including mix (shot 26666 oblate implosion shown here).



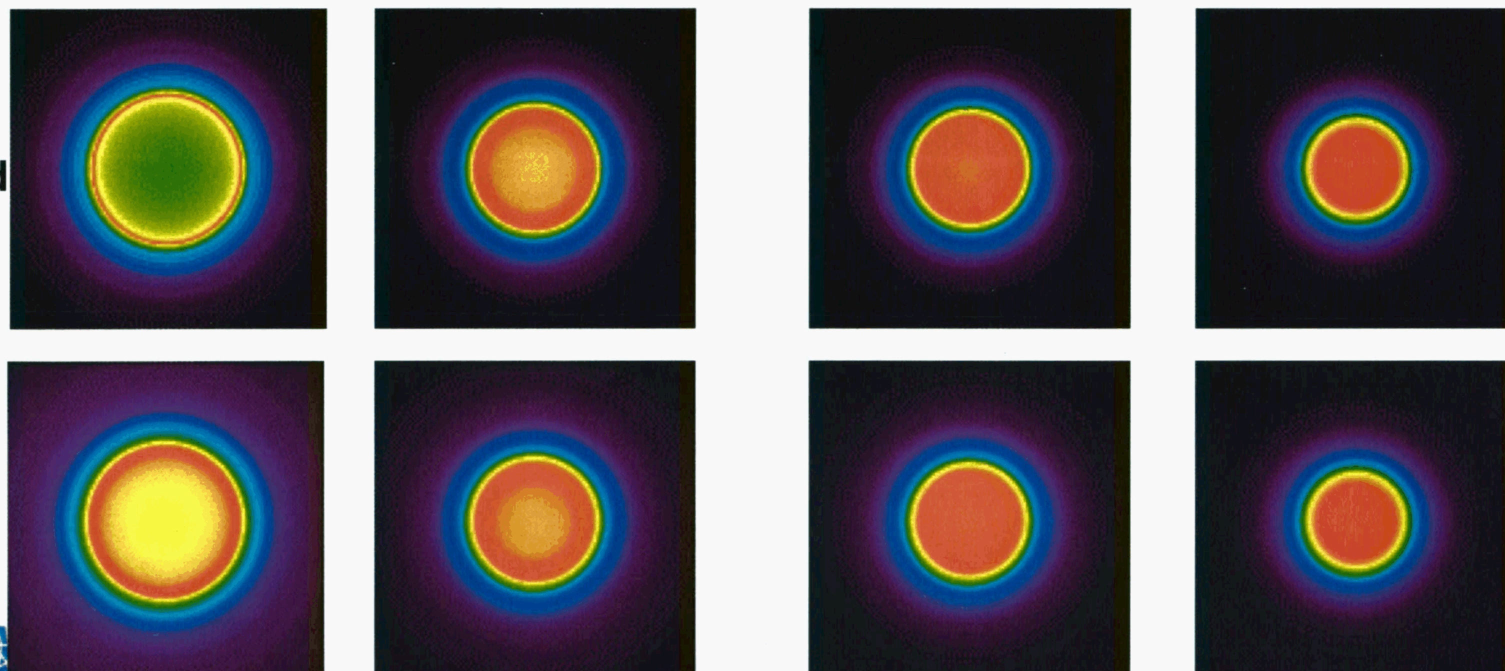
Calculated images are convolved with a gaussian system psf

Spherical GMXI X-ray images show mixing with an $\alpha \sim 0.05$ - 0.07 (ring structure nearly, but not completely filled in)

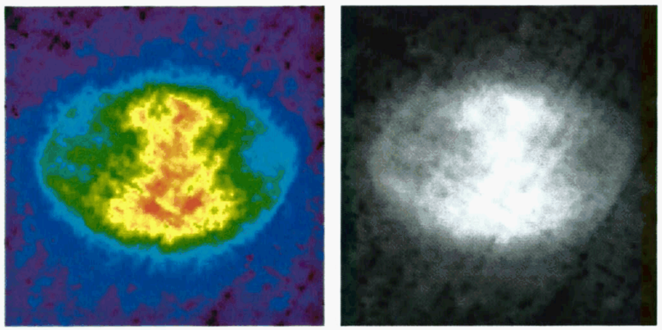


Shot

26668

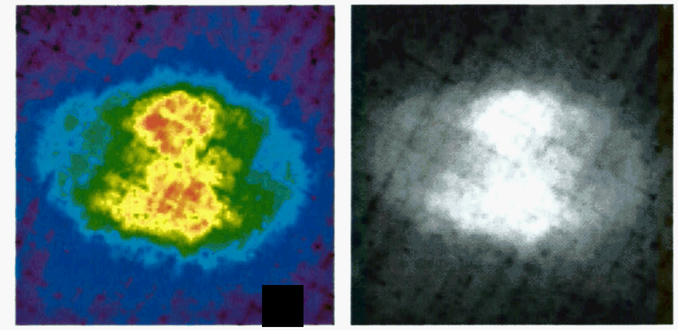


Prolate GMXI X-ray images show mixing with an $\alpha \sim 0.05$ (bright central double cusp band with edge bubbles)



Shot 26665

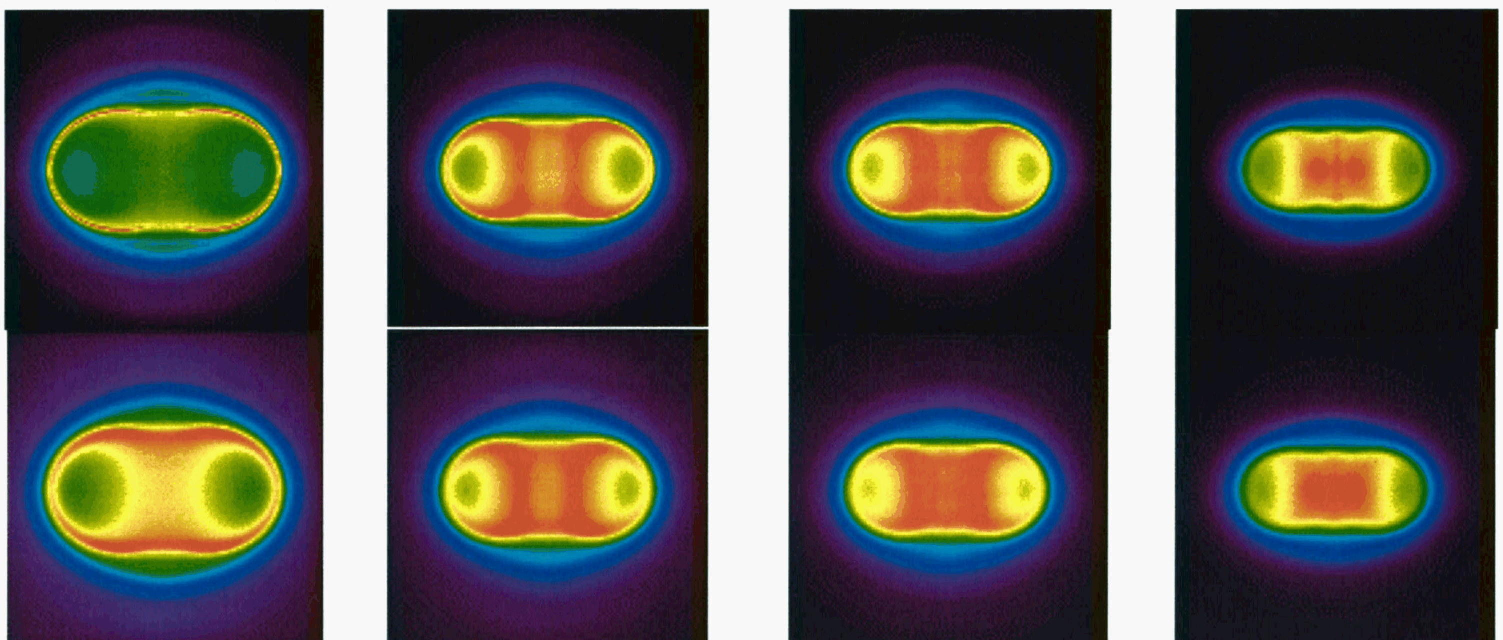
Shot 26670



Unmixed | α=0.05 | α=0.07 | α=0.1

As Calculated

Convolved with 7μm psf



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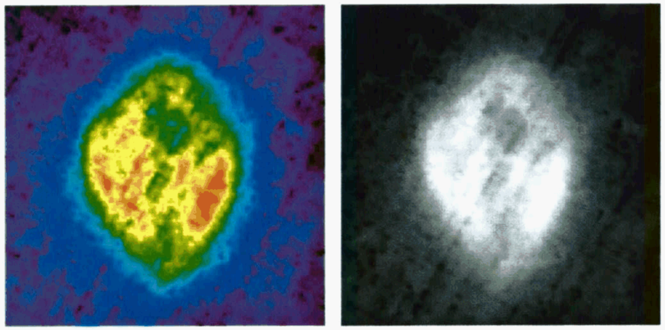
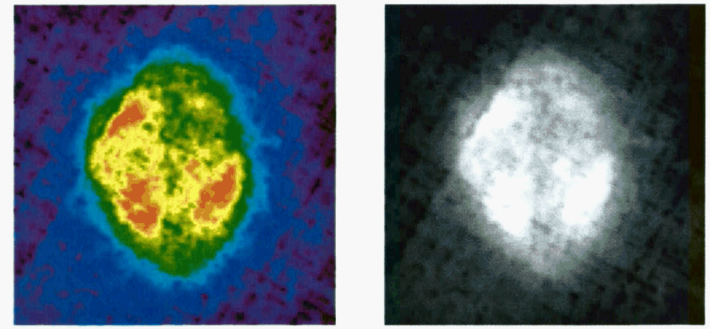
Oblate GMXI X-ray images show mixing with an $\alpha \sim 0.05 - 0.07$ (narrow central valley, moderate top and bottom signal)



Shot 26666

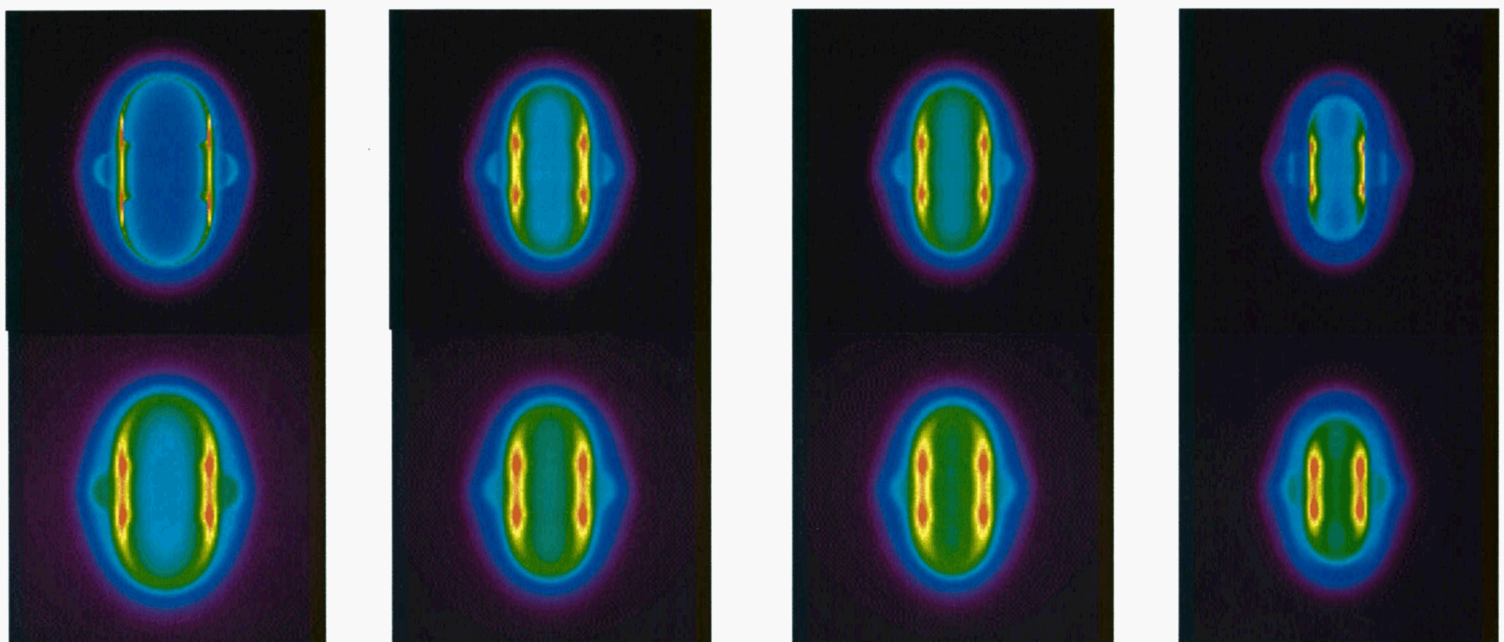
Shot 26669



Unmixed | α=0.05 | α=0.07 | α=0.1

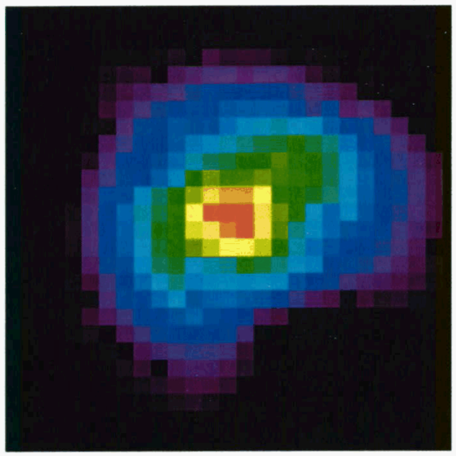
As Calculated

Convolved with 7μm psf

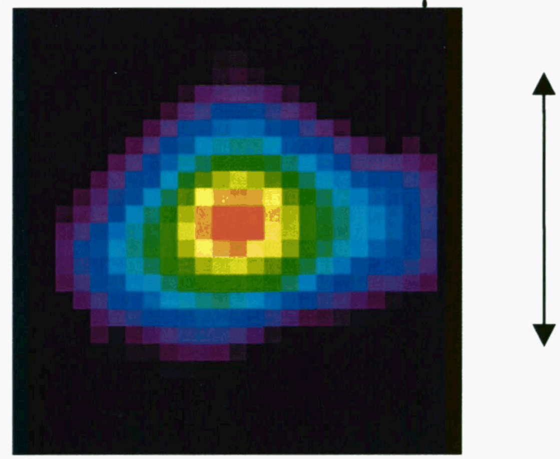


Neutron images from symmetric implosions show a smaller size in agreement with some mixing, but also evidence for some 3D asymmetry.

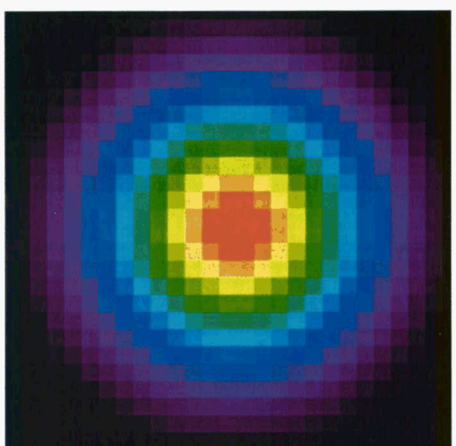
Shot 26664 rms=71μm



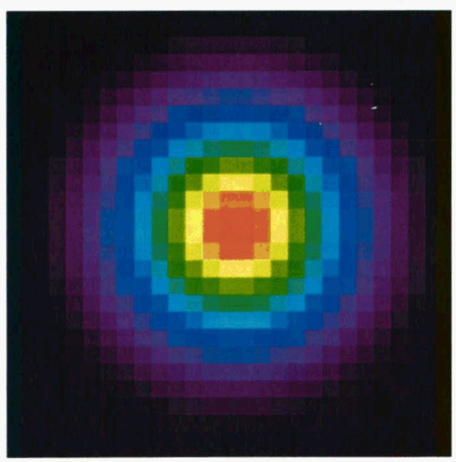
Shot 26667 rms=67μm



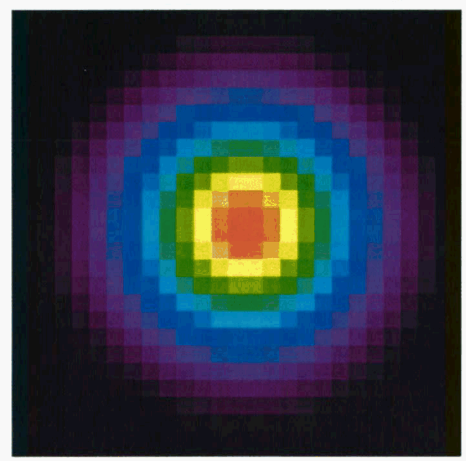
Unmixed rms=81μm



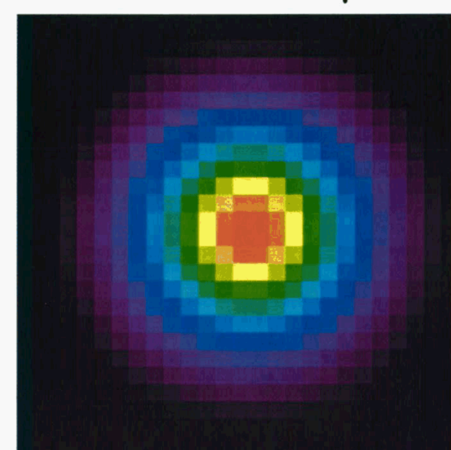
α=0.05 rms=74μm



α=0.07 rms=72μm



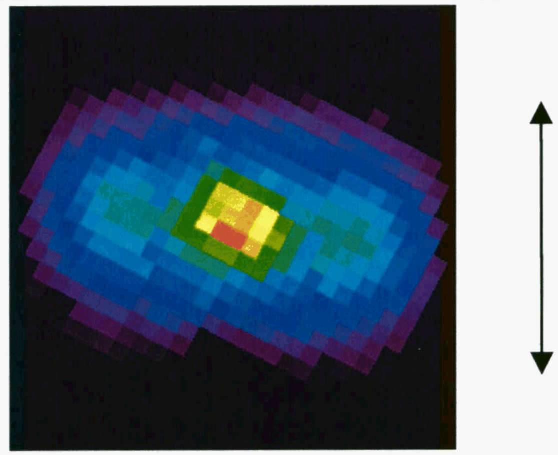
α=0.1 rms=69μm



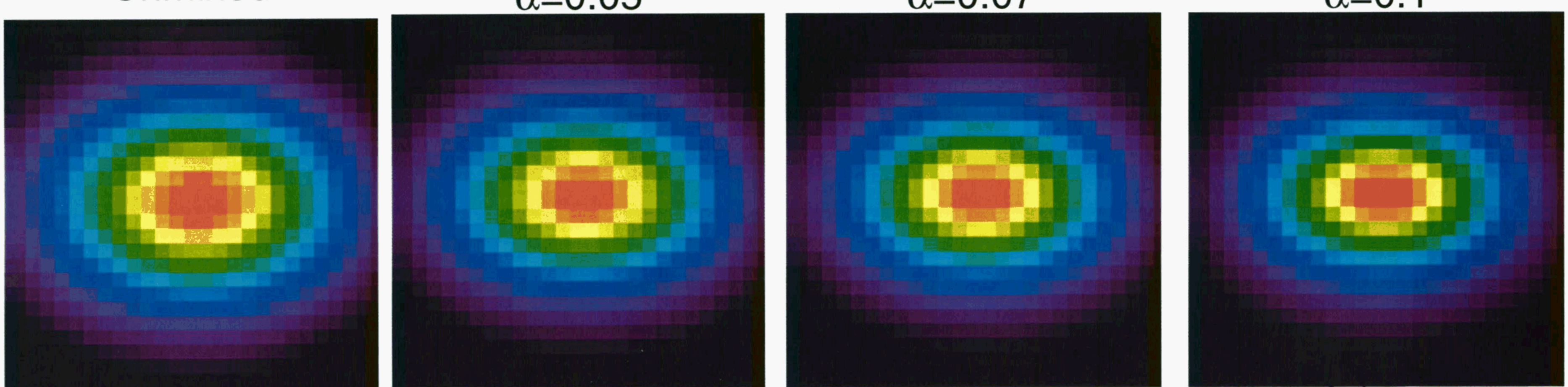
Calculated images are convolved with a gaussian system psf

Neutron images from a prolate implosion show the central peak and elongation along the symmetry axis. Size decreases with mixing.

Shot 26665



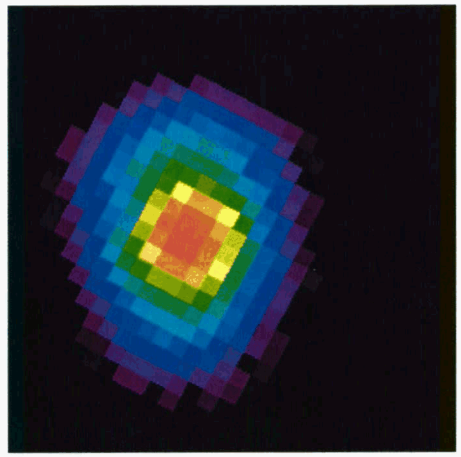
Unmixed α=0.05 α=0.07 α=0.1



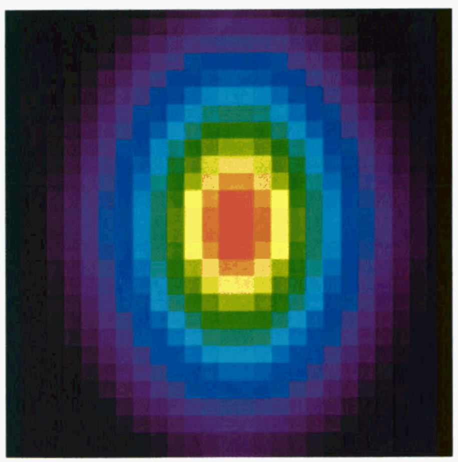
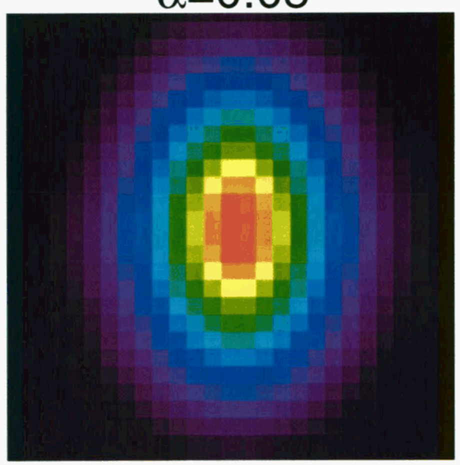
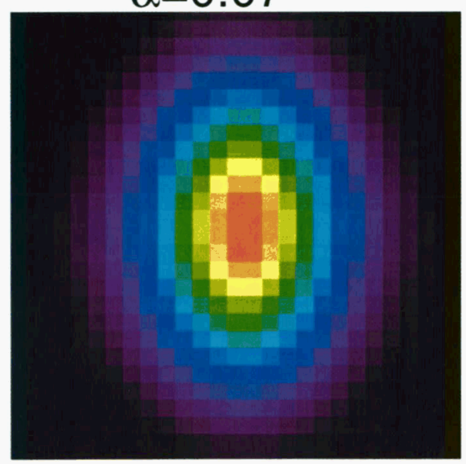
Calculated images are convolved with a gaussian system psf

Neutron images from a oblate implosion show the central peak and elongation along the symmetry axis. Width decreases with mixing.

Shot 26666



100μm

Unmixed	α=0.05	α=0.07	α=0.1
			Unavailable

Calculated images are convolved with a gaussian system psf

The effects of mixing are apparent in yield degradation, burn temperature, X-ray and neutron images.

- Observed yields are consistent with an $\alpha \approx 0.07$-0.08 for both the symmetric and asymmetric drives with 10 atm DT fill and with $\alpha \approx 0.05$-0.07 for 5 atm.
- Measured burn temperatures are nearly independent of measured asymmetry as predicted by the mix model.
- Measured fuel temperatures higher than clean calculated suggest mixing for both types of capsules.
- GMXI X-ray images (5-7 keV) show the effects of mix are consistent with $\alpha \approx$ 0.05-0.07, especially the prolate images.
- Neutron images show a central peak and respond as expected to imposed asymmetries.
- So far we see no strong dependence of mix parameter a with asymmetry.
- **Small scale mix and large scale asymmetry appear uncoupled.**
- Future experiments will test more heavily mixed implosions and may introduce *L=1* asymmetries to test α in a jet.